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VIBRATION AND ACOUSTIC TESTS OF THE RECONFIGURED APOLLO SERVICE MODULE ADAPTED FOR SKYLAB MISSIONS

by

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INTRODUCTION

The Skylab command and service modules are subjected to severe vibration and acoustic environments during launch and boost. Although these dynamic environments have been measured and test requirements verified on Apollo flights, the changes to the service module to adapt Apollo hardware for Skylab missions made prediction of vibration requirements and demonstration of structural adequacy difficult without vehicle-level dynamic tests. The vibration and acoustic tests briefly described herein were used to demonstrate Skylab service module structural integrity for the vibration environment, and to verify analytically developed random vibration criteria for equipment testing.

SPACECRAFT DESCRIPTION

The Skylab spacecraft, as shown in Fig. 1, is similar in exterior appearance to the Apollo spacecraft, consisting of two modules stacked end-to-end. The command module contains the flight crew with associated life support, spacecraft control, stowage, docking, and landing systems. The service module contains the propulsion, electrical power and environmental control systems as well as some scientific experiments. For the

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Skylab mission, the command and service modules were modified to support extended earth orbital missions. Changes to the command module were primarily associated with components, while primary and secondary structures remained the same. None of these component changes required retesting of the command module at the structural assembly level. On the other hand, modifications were quite significant for the service module. The Apollo "J" mission scientific experiments and cryogenic storage tanks, located in bay I of the service module, were replaced with additional propellant storage for the reaction control system (RCS), as well as a scientific equipment shelf and a battery shelf as shown in Fig. 2. The service propulsion system (SPS) propellant required for an earth orbital mission is significantly less than that needed for lunar orbital operation, and allows two of the four SPS propellant tanks and one of the two helium pressurization tanks for the SPS to be removed from the Skylab service module. One of the three fuel cells located in bay IV and the "J" mission batteries on the bay IV aft bulkhead were also removed. These changes completely reconfigured service module bay I and required significant changes to plumbing lines and electrical cables throughout the service module. The service module configuration changes were sufficient to warrant vibration and acoustic testing of a fully assembled Skylab service module.

DYNAMIC ENVIRONMENTS

It should be noted that the Skylab spacecraft will be launched on the Saturn IB booster, whereas the Apollo spacecraft were launched on the Saturn V launch vehicle. However, the vibration and acoustic environments induced by both launch vehicles are generally similar and Apollo design and test requirements account for both Saturn launch vehicles. The vibration induced in the command and service modules during atmospheric flight is intense and the content is both random and sinusoidal. Detailed descriptions of the command and service module vibration environments are presented in Refs. 1, 2, 3, and 4. Initial vibration test requirements

for Skylab hardware were based on extrapolations of Apollo requirements which utilized scaling factors derived from the differences in mass and stiffness for the Apollo and Skylab primary structure.

SKYLAB VIBRATION AND ACOUSTIC TESTS

Because of the extensive modifications to the Apollo service module to adapt it for the Skylab mission, an Apollo service module, modified to the Skylab configuration, was subjected to a series of vibration and acoustic tests in the Manned Spacecraft Center (MSC) Vibration and Acoustic Test Facility. These tests were conducted to verify the design of Skylab structural elements and to refine predicted vibration criteria for new Skylab functional components. In addition, these tests provided margin to verify that Apollo components will function for the new Skylab application. The service module used for this test, designated SM 3D-2, was originally Apollo SM 105, described in Ref. 3. Bay I of the service module was modified to include:

a. A propellant storage module (PSM) and mounting provisions. (The tanks were filled with referee fluids to simulate the launch loading.)

b. A scientific experiment shelf with mass simulated experiments.

c. A battery shelf with the necessary battery cases containing ballast for mass simulation.

d. A new outer shell structural panel, reworked to include the battery and experiment access provision. Plumbing for the RCS propellant storage and portions of wire harnesses were also included on this panel.

Mass simulations of the RCS tanks and engines mounted on the outer shell were used at all four engine locations. At one of these locations, the new Skylab components and associated plumbing were included to provide an interface with the new propellant storage provisions. The additional plumbing and valves required to distribute this propellant to the four engine locations was also installed.

Only one of the SPS helium tanks was installed, and the SPS engine used for this test did not have a nozzle extension. The SPS tanks in bays II and V were filled with referee fluids to simulate the Skylab launch loading conditions.

INSTRUMENTATION

The instrumentation employed during testing consisted of piezoelectric accelerometers and microphones. All output signals for the acoustic and vibration measuring systems were recorded on magnetic tape. The data on each recorded channel consisted of calibration signals, instrumentation ambient noise floor signals, and the test data. More detailed descriptions of the characteristics of the data acquisition systems are presented in Ref. 3.

A total of 180 accelerometers were used to measure vibration responses of primary and secondary structure and responses at the interfaces of new Skylab equipment support structures. A total of 32 microphones was used to measure and control the acoustic tests.

VIBRATION TESTS

Figure 3 shows the overall vibration test configuration. The test fixture was a ring constructed to be rigid in the frequency range of interest, 5 to 35 hertz. An air spring type suspension system was attached to the bottom of this ring. The service module was secured to the top of the ring, and the vibration thrusters were attached as shown in Fig. 3. The suspension system consisted of four air springs located at 90-degree intervals around the ring. The thruster system for longitudinal excitation consisted of four Ling model 310 thrusters attached to the ring. For lateral excitation, two thrusters were attached to the aft end of the service module on primary structure.

Selection of the sinusoidal vibration spectrum for control was difficult because of uncertainties in the response of the test structure. From evaluation of Apollo flight data, it was determined that bending or longitudinal modes of the launch vehicle would produce sinusoidal amplitudes of the spacecraft no greater than 0.2g peak. The flight data also indicated that sinusoids could occur up to 35 hertz and analysis indicated that no component resonances existed below 5 hertz. Therefore, the control procedure that evolved was to subject the service module to a 0.25g peak swept sinusoidal vibration environment over the frequency range of 5 to 35 hertz at a rate of 0.5 octave per minute in the three major axes; longitudinal (X-axis), radial (R-axis: parallel to the horizontal bay I centerline), and tangential (T-axis: orthogonal to the X and R axes and tangential to the horizontal bay I centerline). The acceleration amplitude was controlled at either the service module aft bulkhead or forward bulkhead (whichever was greater). Table 1 summarizes the vibration tests performed in each of the three axes.

Testing in the X and R axes was successfully completed with no anomalies. Three attempts were made to conduct the T-axis test, but anomalous conditions resulted in premature termination of each attempt. During the first two T-axis sweep tests, a resonant condition in the test setup caused test termination due to insufficient thruster control system capability. In the first attempt, the resonant buildup rate was greater than the response speed of the control system. Accordingly, the sweep rate was reduced. In the second attempt, the desired vibration level could not be maintained because of the inability of the amplifier to provide sufficient power to achieve the required thruster force levels. For the third attempt, one control accelerometer was relocated and an amplifier was connected in series with the original amplifier to provide a greater dynamic range. The last T-axis attempt was manually terminated at 25.72 hertz because the test article sustained damage at both thruster attach points.

ACOUSTIC TESTS

The Skylab service module acoustic tests were conducted in the MSC progressive wave acoustic test facility, Ref. 5, which allows variation in spectrum and levels in each of 16 separate ducts located around the service module. Figure 4 shows the test setup. The sound pressure levels used successfully to test the Apollo service module were also used for SM 3D-2. Comparison of flight-measured vibration environments with those generated during Apollo ground tests proved the validity of simulating flight noise levels with acoustic tests. The derivation of the test spectrum is treated in greater detail in Refs. 1, 2, and 3. The acoustic tests were controlled to the levels shown in Fig. 5 by monitoring microphones located in each duct, midway along the service module.

The service module outer shell damage sustained during the vibration testing was repaired to the extent necessary to proceed with the acoustic tests. Damaged parts were not replaced with new parts and the repair did not restore the structure to its full static strength. The service module was then subjected to a progressive wave acoustic environment, which produced random vibration levels in the service module outer shell equal to those experienced during the transonic and maximum dynamic pressure portions of flight. Table 2 summarizes the acoustic tests performed.

TEST RESULTS AND DATA EVALUATION

The service module outer shell structural failure was a result of improper application of the sinusoidal forcing function. The thruster force required to maintain the desired vibration level and the configuration of the thruster attachment (single point) to the test article resulted in local overloading of the structure. Evaluation of the data obtained during the attempts to conduct the T-axis test resulted in the conclusion that the test setup exhibited a unique resonance at approximately 26 hertz with an antinode condition at the thruster attachment

plane. The single point attachment of the thrusters is unrealistic when compared to the actual load path across a spacecraft module-to-module interface. Vibration loads are transmitted over the entire interface, rather than at two discrete points. Therefore, the local loading conditions producing the outer shell failure were not considered representative of flight conditions, and the failure does not represent a structural design deficiency. Further attempts to complete the T-axis testing were terminated because of program schedule considerations. The risk involved with not having tested in the range of 25 to 35 hertz for the T axis was considered to be very small since Apollo flight data indicated only minor sinusoidal forcing functions in this frequency range. Moreover, the absence of equipment resonances over 25 hertz during the R-axis test and the similarity of the equipment in the T and R directions tended to indicate that T-axis resonances were unlikely.

Table 3 summarizes the sinusoidal vibration test criteria derived from the SM 3D-2 tests for the bay-I batteries, the scientific experiment shelf, and the PSM. These vibration criteria were established by adjusting the X, R, and T axis response vibration data for SM 3D-2 by the correction factors defined in Fig. 6. The correction factors represent a 2-sigma peak amplitude envelope of a composite of several measurements recorded on two Apollo flights. These factors were used to account for differences between SM 3D-2 vibration inputs and the in-flight service module sinusoidal forcing function.

The data recorded during the acoustic tests from all accelerometers were reduced to acceleration spectral density plots which were then grouped into composites to represent the maximum environments for each Skylab item of equipment on SM 3D-2. Figure 7 presents a typical composite of several measurements and the resulting envelope which was then used as the component random vibration test criteria.

The SM 3D-2 tests allowed derivation or refinement of vibration test requirements for approximately ten Skylab equipment items and assemblies.

CONCLUSION

The Skylab SM 3D-2 vibration and acoustic tests were successfully completed and the required vibration response data obtained. Structural integrity of the Skylab service module was demonstrated for the vibration environment and evaluations of measured data provided the necessary refinement to predicted Skylab equipment test requirements.

TABLE 1.- SINUSOIDAL SWEEP VIBRATION TESTS[a]

Run number	Axis	Planned frequency band, Hz	Test run time, sec	Sweep rate, octaves/min	Comments
1	X	5-35	292.229	0.568	Successful test.
2	R	5-35	292.230	0.568	Successful test.
3	T	5-25	253.623	0.568	Aborted at a frequency of 27.06 hertz.
4	T	10-35	285.846	0.2845	Aborted at a frequency of 25.90 hertz.
5	T	10-35	230.012	0.2845	Aborted at a frequency of 25.72 hertz. Test article damaged.

[a]Input level for tests was 0.25g peak.

TABLE 2.- ACOUSTIC TEST SUMMARY

Run number	Average overall sound pressure level, dB	Test run time, sec	Comments
1	146	60	Successful test.
2	152	15	Successful test; response measurement ranging confirmed.
3	152	15	The second short high-level run was made to optimize spectrum levels.
4	152	112	Successful long duration run; all required excitation time accumulated.
	156	10	
ACCUMULATED EXCITATION TIMES:			
	146	60	
	152	142	
	156	10	
		Total 212	

TABLE 3.- SKYLAB SINUSOIDAL TEST CRITERIA DERIVED FROM SM 3D-2 ACCELERATION DATA

Location	Amplitude		Frequency, Hz
	g peak	in. D.A.	
Inputs to batteries on bay I battery shelf			
X-axis		0.13	5 - 15
	0.15		15 - 20
	0.8		20 - 35
R-axis	0.25		5 - 15
	0.4		15 - 20
	0.25		20 - 35
T-axis		0.115	5 - 16
	1.5		16 - 20
	0.35		20 - 35
Inputs to equipment on scientific experiment shelf			
X-axis	0.25		5 - 14
		0.025	14 - 27.5
	1.0		27.5 - 32.5
	0.25		32.5 - 35
R and T axes	0.25		5 - 35
Inputs to PSM at structural attach points			
X, R, and T axes	0.25		5 - 35

REFERENCES

1. D. E. Newbrough, R. A. Colonna, J. R. West, Jr., "Development and Verification of the Apollo Command and Service module Vibration Test Requirements," Shock and Vibration Bull. NO. 37, Part 5, 1968.

2. D. E. Newbrough, Murray Bernstein, and Eugene F. Baird, "Development and Verification of the Apollo Lunar Module Vibration Test requirements," Shock and Vibration Bull. No. 37, Part 5, 1968.

3. A. E. Chirby, R. A Stevens, W. R. Wood, Jr., "Apollo CSM Dynamic Test Program," Shock and Vibration Bull. No. 39, Part 2, 1969.

4. C. L. Stevens, "Vibration Response of Apollo Shell Structures to Acoustic and Aerodynamic Noise," Proceedings of the 13th Meeting of the Institute of Environmental Sciences, Vol. II, 1967.

5. R. J. Wren et al., "Concept, Design, and Performance of the Spacecraft Acoustic Laboratory," Shock and Vibration Bull. No. 37, Part 5, 1968.

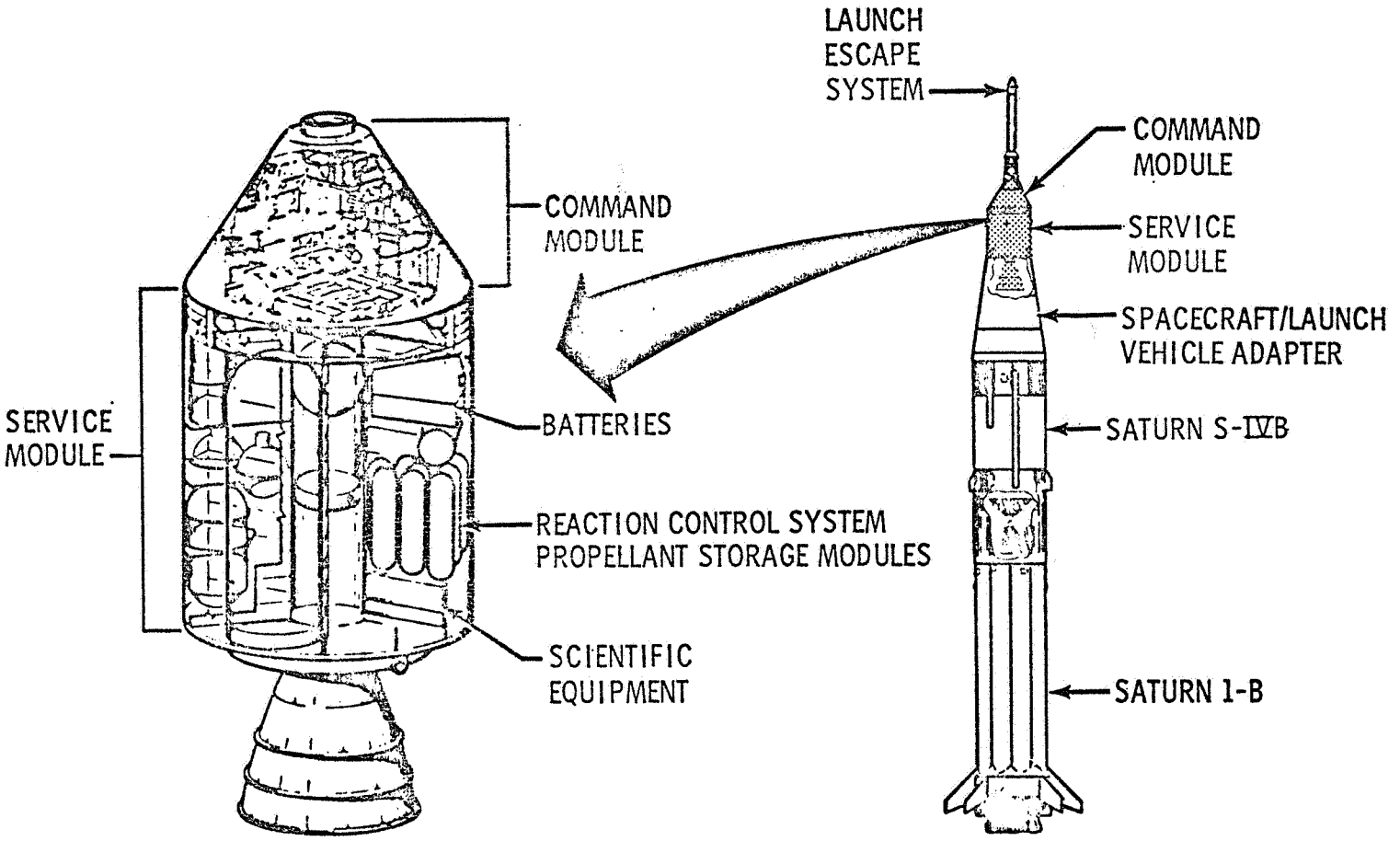

FIGURE 1.- SKYLAB SPACECRAFT AND LAUNCH VEHICLE.

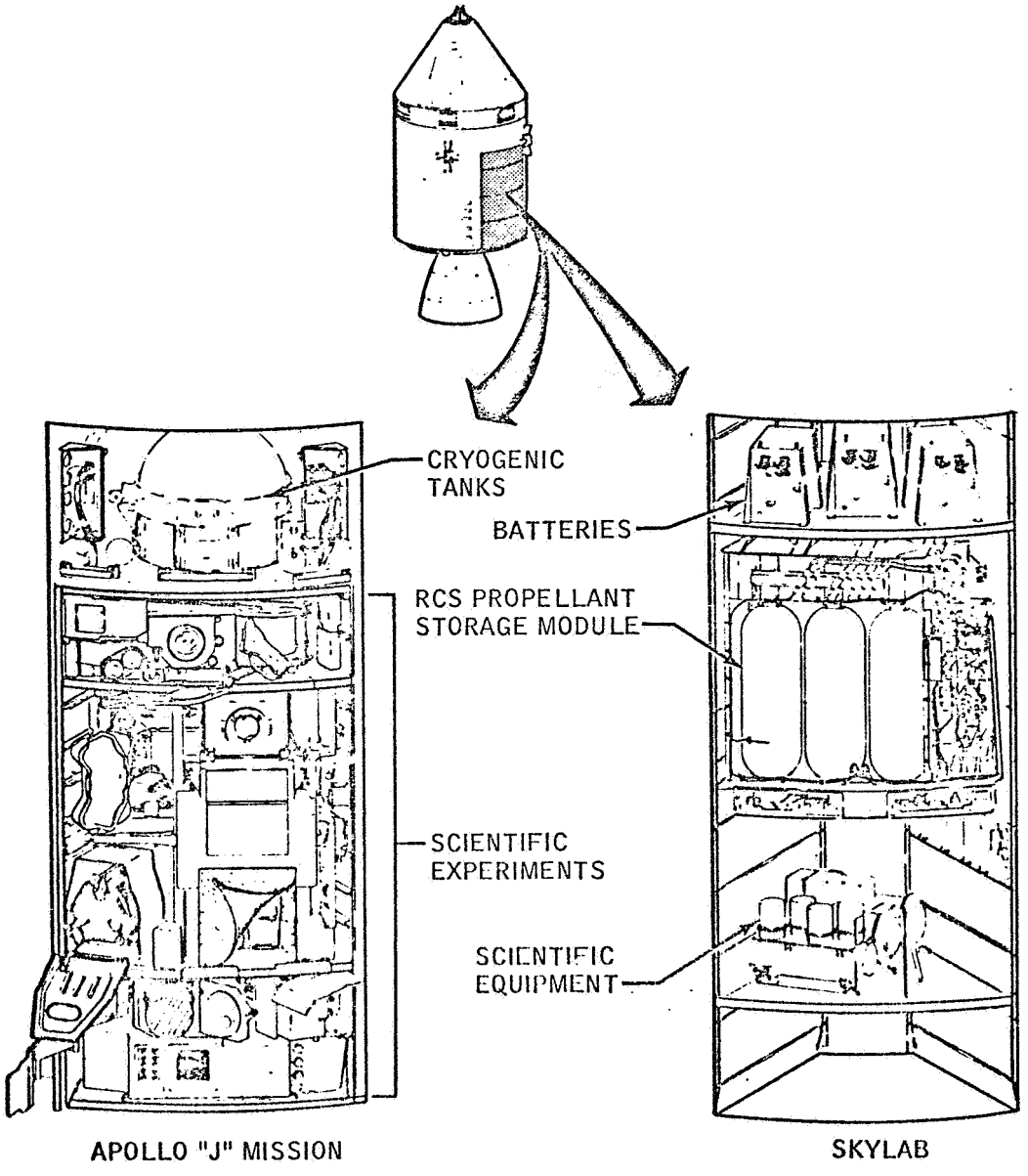

FIGURE 2.- SERVICE MODULE BAY I - APOLLO "J" MISSIONS AND SKYLAB

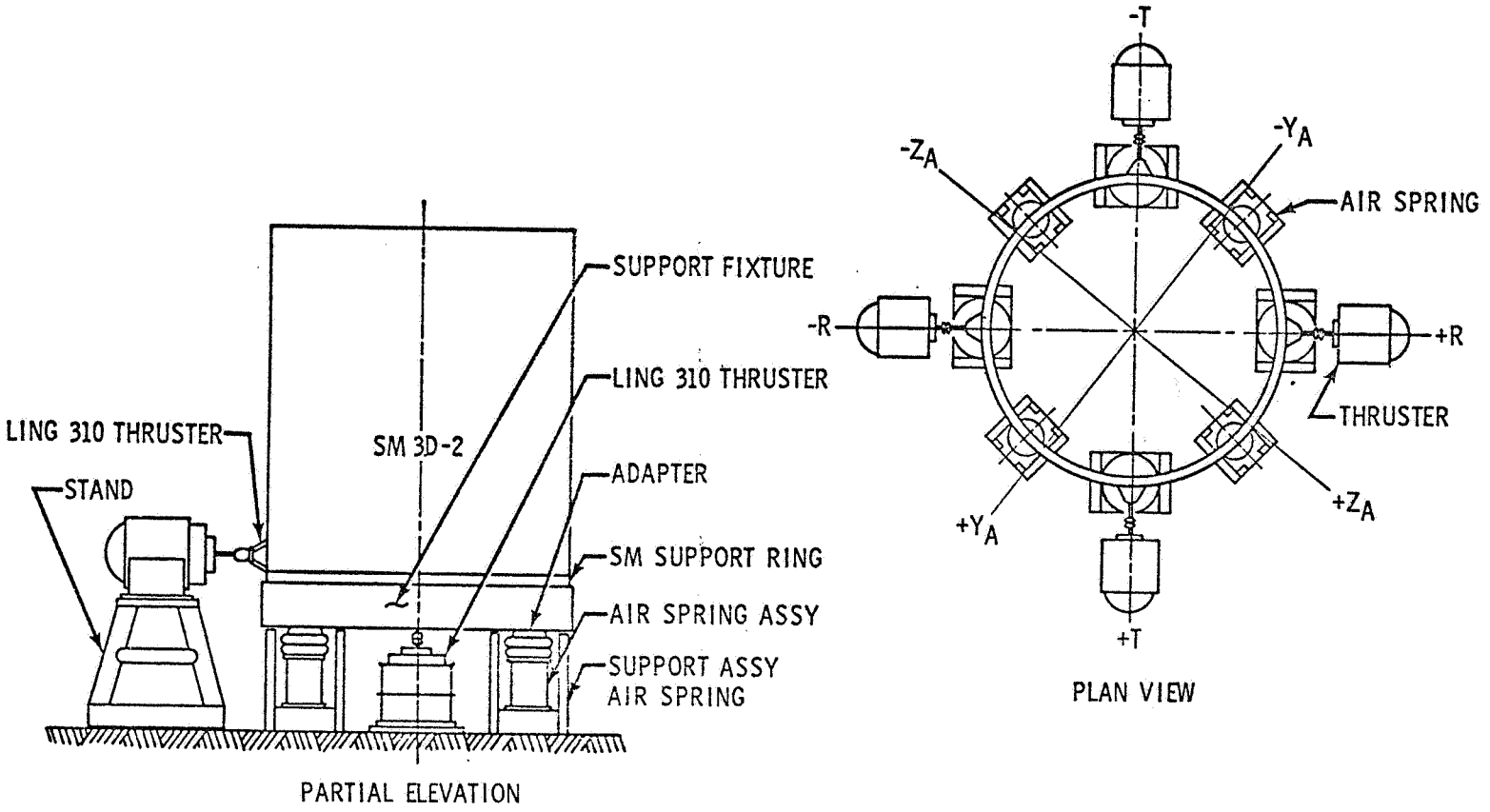

FIGURE 3. - SM 3D-2 VIBRATION TEST CONFIGURATION

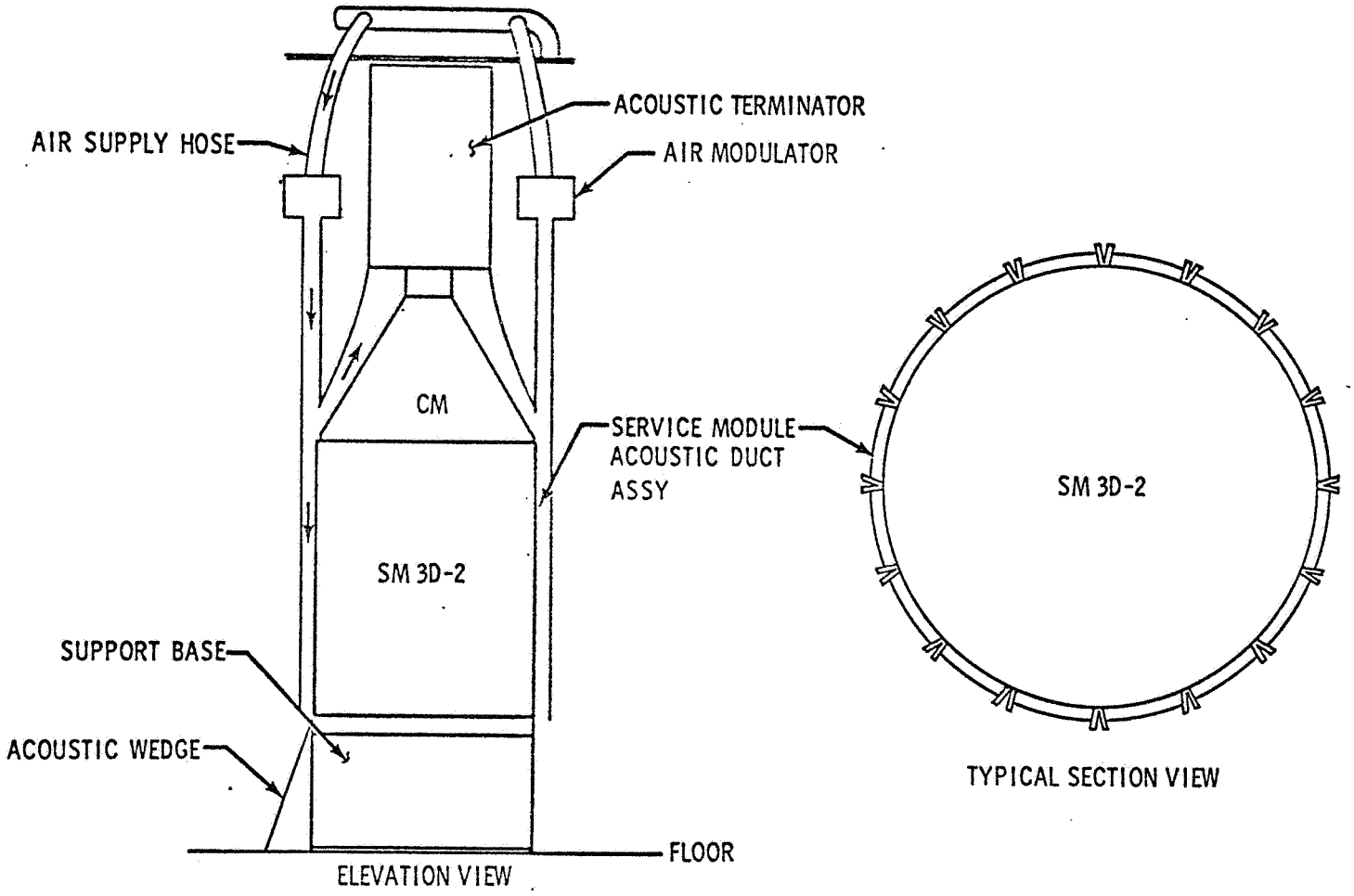

FIGURE 4.- ACOUSTIC TEST ASSEMBLY, MODIFIED SERVICE MODULE 3D-2.

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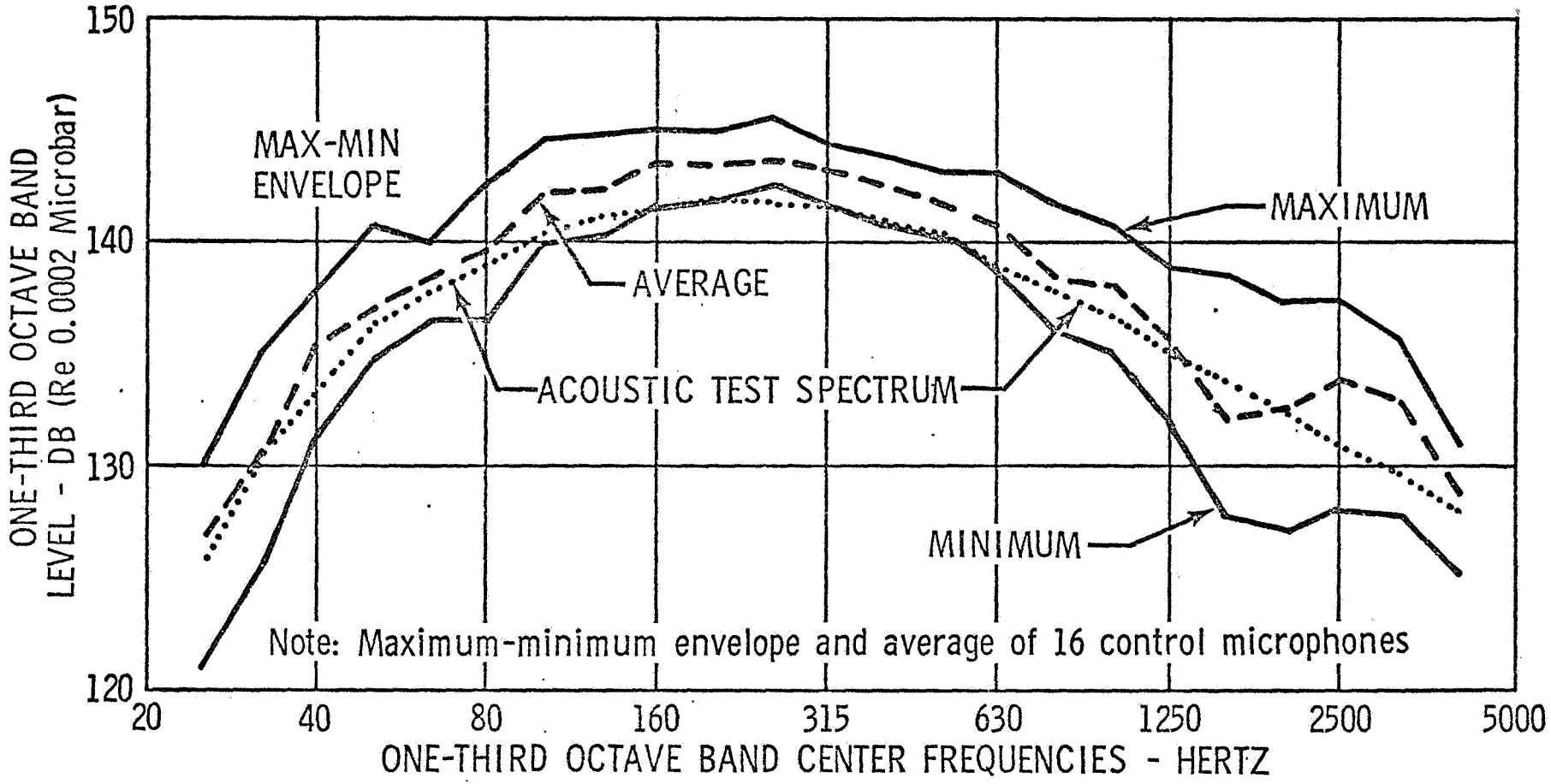

FIGURE 5. - ACOUSTIC SPECTRA - CONTROL DATA FROM SM 3D-2

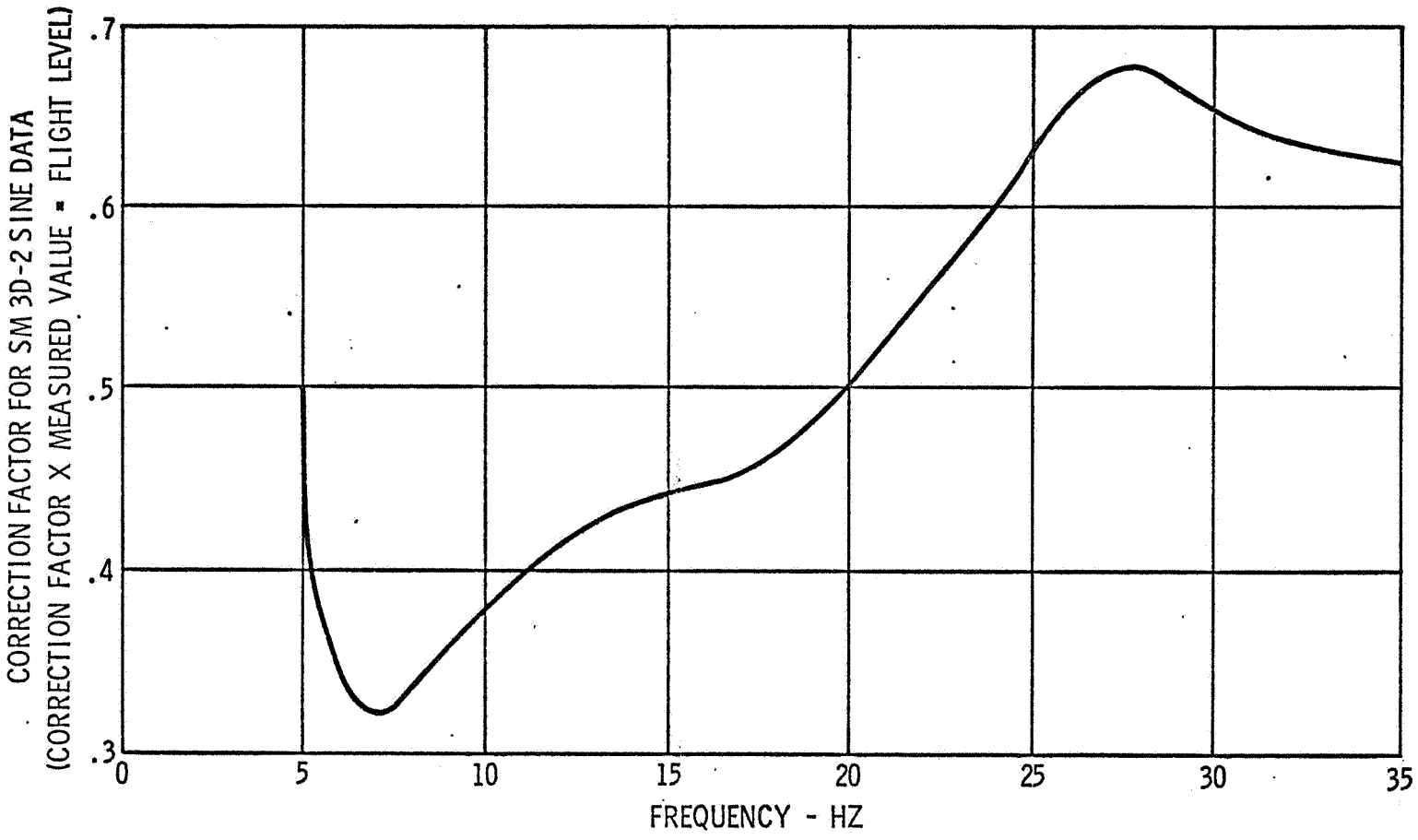

FIGURE 6. - CORRECTION FACTOR FOR SM 3D-2 SINUSOIDAL DATA

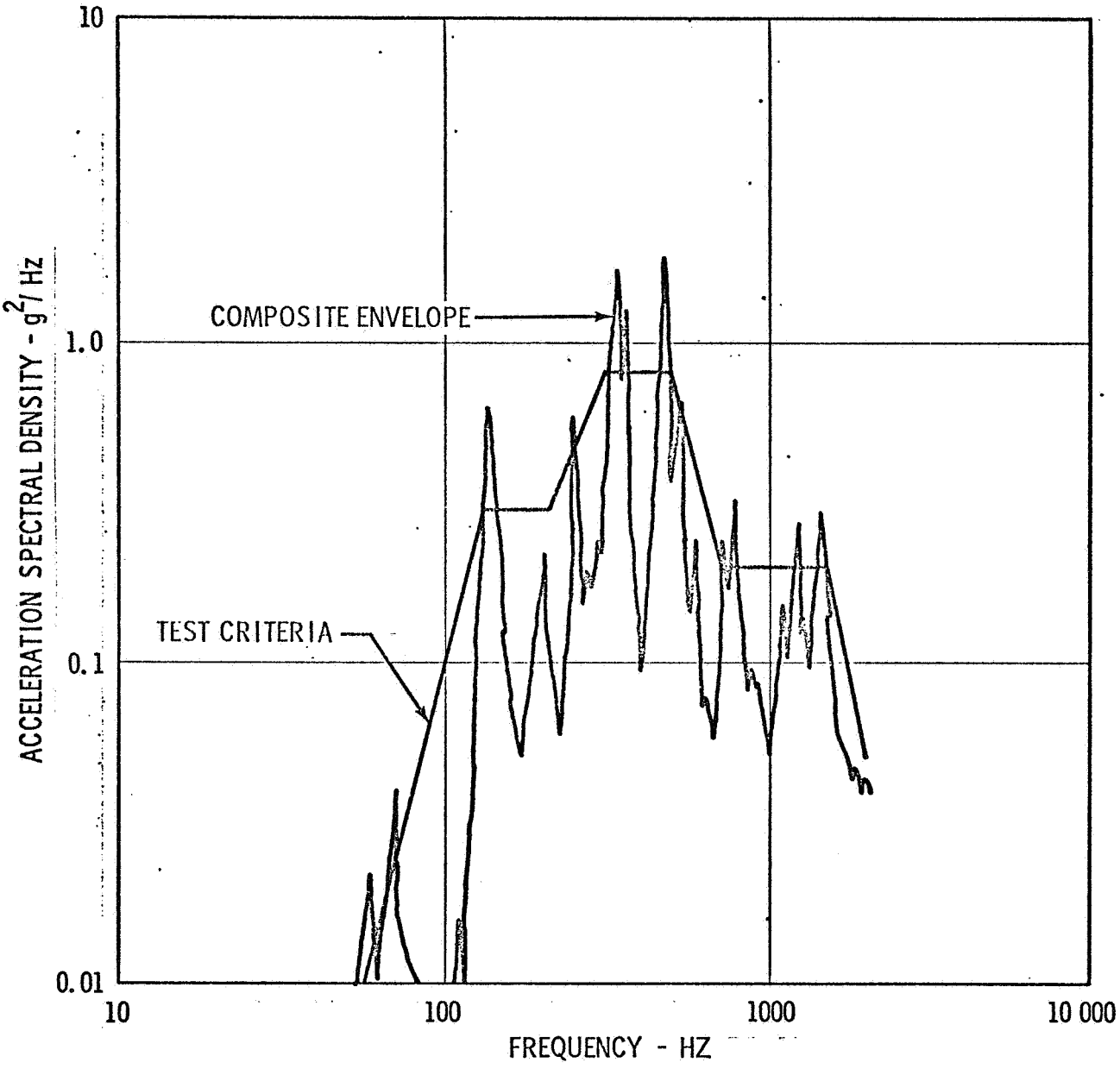

FIGURE 7. - RANDOM VIBRATION - TYPICAL COMPOSITE AND CORRESPONDING TEST REQUIREMENT ENVELOPE